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GOES I-M AND BEYOND: SCIENCE REQUIREMENTS AND TECHNOLOGY CHALLENGES

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MAJOR EARTH OBSERVATION PARAMETERS MEASURED
FROM GEOSYNCHRONOUS SATELLITES

The most significant parameters that are expected to be measured from geosynchronous orbit as a function of spectral region from the ultraviolet through the microwave (≥ 5GHz) are shown below. The spectral regions that are the primary contributors are shown with a "P" and the other regions that contribute in a secondary role are shown with an "S". In every case more than one spectral region is involved with the measurement of each parameter. The most effective measurement system will often combine the data from more than one instrument. Since many of the parameters are used to investigate a scientific event the simultaneous data from numerous instruments is required. Also, these data can be combined with low orbiting measurements to further improve accuracy, resolution, etc. Thus, there will be a requirement to co-locate the measurements from low earth and geosynchronous orbits which will place a high demand on the earth location accuracy from each orbit, usually at the level of the highest spatial resolution used in the analysis.

	SPECTRAL REGION				
PARAMETERS	UV	VISIBLE	REFLECTED IR	EMITTED IR	MICROWAVE (≥5 GHz)
SURFACE TEMPERATURE		S		P	P
TEMPERATURE AND MOISTURE PROFILES		S		P	P
WINDS					
• CLOUD MOTIONS		P		P	S
• MOISTURE MOTIONS				P	
• FROM MASS FIELD		S		P	P
CLOUD PROPERTIES					
• HEIGHT		P		P	
• PHASE (ICE VS. WATER)		P	P		P
• TYPE		P	P	P	S
• AMOUNT		P		P	
PRECIPITATION		P		P	P
LIGHTNING		P			
WATER AND AIR POLLUTION		P	P		
OZONE	P			P	
ICE/SNOW		P	P		P
SOIL MOISTURE			P	P	P
OCEAN COLOR		P			
EARTH RESOURCES		P	P	P	

P – PRIMARY S - SECONDARY

SEVERE LOCAL STORM OBSERVATIONAL GUIDELINES

The table below is a set of observational guidelines for severe local storms that have reached the mature convective phase (i.e. actually producing severe weather conditions like hail, tornadoes, and/or strong surface winds). The guidelines represent what parameters are required and their spatial, temporal, and vertical resolution and accuracy. The guidelines represent what is required to monitor the thunderstorms that are in progress and the surrounding atmosphere within which more storms could be produced. Nearly all of the guidelines have a range of values. Most of the improvements to understanding and prediction of severe local storm events are expected to come as observations move from the low resolution end to the high resolution end of each range. Although observations outside the low resolution limits can still be of benefit, the greatest increase in improvement should come from the observations within the range. Likewise, to improve observational performance beyond the upper limit is not expected to result in much improvement in the basic understanding or the forecasting of these events.

The earth coverage, even at the highest temporal resolution, should be at least 1000x1000 km. Therefore, the combination of resolution, coverage and accuracy will place high demands on the instruments and the rest of satellite system (e.g. navigation, communications).

In general, these guidelines represent the most demanding set that is connected with studying atmospheric processes. When these guidelines are satisfied, then just about all of the guidelines associated with mesoscale and regional scale atmospheric circulations are satisfied including data sets that could be used in atmospheric models. Many guidelines would also be satisfied concerning the diurnal measurement of parameters connected with global change (e.g. clouds). For global change, large areas (e.g. full disk) would be monitored at lower temporal resolution (e.g. 5-60 minutes).

Parameter	Resolution: Spatial (km)	Vertical (km)	Temporal (min)	Absolute Accuracy
Temperature:				
o Surface	5-15		10-30	±1-2K[a]
o Profile, General	10-50	1-5[b]	30-120	±1-2K[a]
o Profile, Thunderstorm and Immediate Vicinity	5-25	1-5[b]	1-10	±1-2K[a]
Moisture:				
o Profile, General	10-50	1-5[b]	30-120	±5-15RH
o Profile, Thunderstorm and Immediate Vicinity	5-25	1-5[b]	1-10	±5-15%RH
o Lower Tropospheric Moisture Gradient (e.g., dry line)	3-15		5-30	±10-25%RH[a]
Surface Pressure:				
o General	10-50		30-120	0.5-1.0 mb[a]
o Thunderstorm and Immediate Vicinity	5-25		1-10	0.5-1.0 mb[a]
Winds:				
o Boundary Layer	5-20	0.2-1	5-30	±1-3m/sec
o Above Boundary Layer	10-50	1-5	15-60	±1-3m/sec
Precipitation:				
o Rate	3-50		3-30	±20-50%
o Type	1-10		1-10	Rain/Hail
o Yes/No	5-50		6-60	
Cloud Top Height	0.5-10	0.25	0.5-15	±250-500m

[a]Relative accuracy is one-half these values

[b]Need 0.2 km vertical resolution for inversions

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FUTURE GEOSYNCHRONOUS SATELLITES - MAJOR INSTRUMENT REQUIREMENTS

The table on the following page describes the major earth-viewing geosynchronous satellite remote sensing requirements that result from the parameter requirements like what is shown on the previous page. This is the best that we can envision based on the current state of the art. There are still areas where further progress is needed which will be specified later. There are numerous instances in the following table where the remote sensing requirements are different than the parameter requirements. A good example is what is needed to track clouds to infer the winds as contrasted to the actual spatial and temporal resolution of the wind fields. The instrument temporal and spatial resolution requirements are much greater than the wind field resolutions since the instrumental resolutions are dependent on accurately locating and following the progress of small cloud elements to determine the winds.

There are many places in the table where a wide range of resolutions is indicated. This is because a number of uses are expected and the range reflects the resolutions associated with those uses. The principal requirements that are expected to drive instrument and spacecraft system design in the table are as follows:

1) The microwave spatial resolution for precipitation, temperature, and moisture profiles. Even if high frequency microwave window channels (e.g. 150 GHz) were used for precipitation, an antenna size of about 70 m would be needed to achieve 1 km resolution. The use of lower frequencies would require proportionally larger antennas.

2) The combination of spectral and spatial resolution, radiometric resolution and sensitivity, and coverage requirements associated with infrared temperature and moisture profiling.

3) The combination of spatial resolution (particularly infrared), image frequency, and radiometric sensitivity associated with the measurement of surface temperature, cloud properties, and precipitation using visible and infrared imagery.

4) The combination of spatial resolution and sensitivity requirements associated with ocean color and vegetation measurements.

Future Geosynchronous Satellites

Major Instrument Requirements

Parameter	Primary Instrument Type	Resolution: Spatial (km)	Resolution: Temporal (min)	Resolution: Spectral	Nadir Earth Coverage (km)	Typical Sensitivity Values
Temperature Surface	o Visible and IR o Imaging	≤1	≤10 (1000x1000 km) ≤60 (full disk)	≤50 nm	1000x1000[1]	≤0.1K NEΔT at 300K (IR channels)
Profiles	o IR Profiling o Microwave (MW) profiling	≤5 (IR) 5-25 (MW)	1-10 (IR) 1-30 (MW) - up to 1000x1000 km	0.2-40 cm^{-1} (IR) 200-500 MHz (MW)	1000x1000[1]	≤0.1K NEΔT -normal scene temperature for a channel (IR) ≤0.25K NEΔT -normal scene temperature for a channel (MW)
Moisture Profiles	o IR Profiling o MW Profiling	≤5 (IR) 5-25 (MW)	1-10 (IR) 1-30 (MW) - up to 1000x1000 km	1-40 cm^{-1} (IR) 1 GHz (MW)	1000x1000[1]	Same as temperature profiles
Ozone	o UV spectro-meter o IR Imaging or Profiling	10-50	10-60	2 nm (UV) 0.35-5 cm^{-1} (IR)	1000x1000[1]	1% within 100-600 Dobson units (UV) 0.1 K NEΔT at 200K (IR)
Winds	o Visible, IR and MW imaging o IR and MW Temp. profiling	0.2-2 5-25	1-10 10-180	≥20 nm (IR) Same as temp. profiling	1000x1000[1]	1K NEΔT at 200K (IR) Same as temp. profiles
Precipitation	Visible, IR and MW imaging	0.5-5 (vis & IR) 1-10 (MW)	1-5 (vis & IR) 3-30 (MW)	≥20 nm (vis & IR) 0.5-1 GHz (MW)	500x500[1]	0.5K NEΔT at 200K (IR) 1K NEΔT at 200K (MW)
Cloud Properties (e.g. amount, type, and height)	Visible and IR Imaging	0.2-1	0.25-30	1-50 nm	500x500[1]	0.5 K NEΔT at 200K (IR)
Lightning	Visible and Near IR Imagery	1-10	1 millisecond	1 nm	1000x1000[1]	4.5 μjoules m^{-2} ster
Sulfur Dioxide (volcanic eruption)	UV spectrometer	10-50	10-60	1 nm	1000x1000[1]	≤3 milliatm. cm of SO_2
Ocean Color	Visible and IR Imaging	0.1-0.5	30-60	10-20 nm	100x100 up to 1000x1000	0.003 MW cm^{-2} μ^{-1} $ster^{-1}$
Vegetation	Visible and IR Imaging	0.03-0.5	30-60	10-20 nm	50x50 up to 500x500	0.003 MW cm^{-2} μ^{-1} $ster^{-1}$

[1]Minimum coverage needed--up to full disk required for maximum coverage

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RAPID CONVECTIVE CELL GROWTH

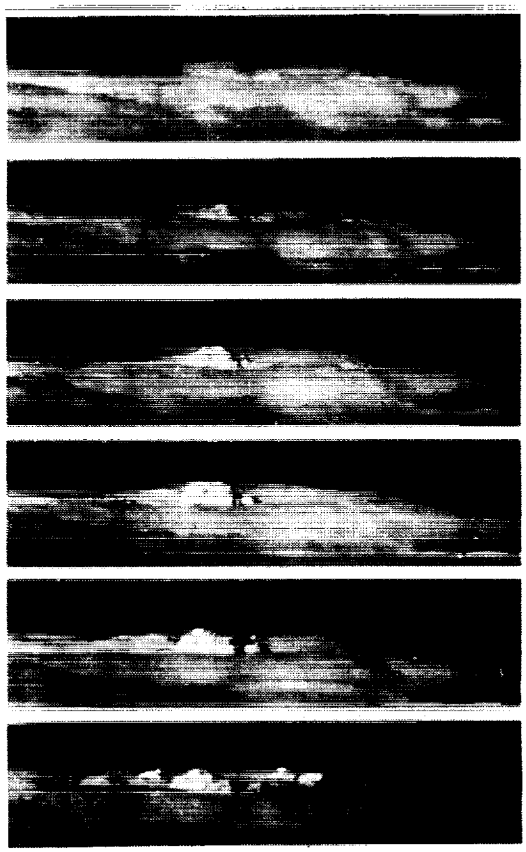
The following series of aircraft photographs of the tops of a violent thunderstorm illustrates the need for extremely frequent imaging to accurately depict what is occurring during an extreme event. It is crucial that we design our satellite instruments to capture extreme events because they are the ones that have the greatest impact. Hail and tornadoes were produced during the lifetime of this convective complex.

These rapidly growing and dissipating domes penetrated into the lower stratosphere in extreme southern Texas on May 12, 1972. From about 90 km away and with the aircraft near the level of the anvil, a dome near the center of each photograph grew rapidly between 2330 and 2331 GMT and had begun to collapse at 2332. At 2331:30 the height of the 7.7 km wide dome was 2.3 km above the cirrostratus anvil. Between 2330 and 2330:30 the vertical growth rate was 27 m sec^{-1} and slowed to 18 m sec^{-1} over the next 30-sec interval. New cells can be seen beginning to grow on both sides of the principal dome near the end of the sequence.

These extreme growth rates and the cell dimensions can provide guidelines for the development of future geosynchronous satellite instrumentation. From the analysis of this case and other similar events, we have concluded that ≤ 1 km visible and infrared imaging resolution is required at 15 second intervals to properly monitor the tops of violent convection.

PHOTOGRAPHED FROM A LEAR JET AT 45,000 FT.

MAY 12, 1972



2330 GMT

2330:30 GMT

2331 GMT

2331:30 GMT

2332 GMT

2332:30 GMT

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FUTURE GEOSYNCHRONOUS SATELLITE REQUIREMENTS

A. Space System Requirements

1. Absolute Earth Location (3σ)

Within 1 pixel of the highest resolution measurement made on the spacecraft.

2. Imaging Within Image Stability and Image-to-Image Registration (3σ)

Within 30% of the highest resolution measurement made on the spacecraft.

3. Instrument-to-Instrument Alignment Knowledge (3σ)

Within 1 pixel of the highest resolution used in the analyses of measurements from the combined instruments.

4. Absolute Pointing Accuracy - Within 5% of the smallest size area covered from any sensor on the spacecraft.

B. General Instrument Requirements

1. Imaging -

a. Channel-to-channel registration (3σ) - Within 30% of the highest resolution pixel in the instrument. This could be a system requirement if there are very high frequency sources of spacecraft jitter.

b. Knowledge of diffraction effects out to the 99% encircled energy level.

c. System MTF at least to the GOES I-M imager level.

2. IR Profiling

a. Channel-to-channel registration (3σ) - Within 10%

b. Knowledge of diffraction effects out to 99.5% the encircled energy level.

c. High spatial resolution cloud knowledge out to the 99% encircled energy level.

3. Microwave Profiling

a. Same as items 1 and 2 for IR profiling

b. Beam efficiency within Aries disk - $\geq$97%.

Examples of Major Technological Challenges for the Next 25 Years

System

- o Earth Location Accuracy
- o Image Stability
- o Motion Compensation for Diverse Sensors on Same Spacecraft Implementing Complex Measurement Scenarios
- o Rapid and Accurate Parameter Determination and Widespread Information Dissemination
- o Longer Lifetimes (includes servicing)

Visible and Infrared Imaging and Infrared Profiling

- o Detector Technology - Stability, Sensitivity, Arrays, Spectral Knowledge, etc.
- o Calibration - Large Mirrors
- o Coolers (radiative, refrigerators, cryogen)
- o Pushing Spectral Resolution Limits (filters, interferometers, spectrometers, Fabry-Perot)
- o Scanning Mechanisms - Stability
- o Minimize Diffraction Effects
- o Channel-to-Channel Registration

Microwave Imaging and Profiling

- o Develop and Maintain Antenna Surface Tolerances ($\leq 1/20\lambda$)
- o Earth Coverage of $\geq$1000x1000 km (up to full disk) Within Temporal Limits Using Large Antennas
- o Unfurling Large Antennas and Maintaining Surface Tolerances (e.g. 50 m Antenna Measuring at 220 GHz)
- o Minimize Antenna Movement Effects on the Performance of Other Sensors
- o Synthetic Aperture Microwave

Major Areas for Further Long-Range ($\geq$25 years) Development in Geosynchronous Orbit

- o Active Sensing (e.g. lidar, radar)
  - o Pressure (surface and profiles)
  - o Temperature and moisture profile vertical resolution and accuracy
  - o Precipitation

- o Very Large Microwave Antennas ($\geq$100m) for Low Frequency Measurements ($\leq$40 GHz)
- o Surface Energy Augmentation from Space